PERFORMANCE EVALUATION OF STEEL BRIDGE COATING WITH BINDER TYPE

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ABSTRACT

Performance of various coating systems including chlorinated rubber and epoxy/urethane used the most for steel structures of highway in Korea was evaluated by exposing test specimen to complex deterioration factors such as ultraviolet ray, moisture, freeze-thaw cycle and salt. Deterioration degree of specimen was evaluated by inspection for chalking, checking and rust, and measurement of color differences and adhesion. In overall coating performances containing corrosion resistance, photochemical stability, and adhesion, ceramic/urethane, moisture-curing urethane/urethane, etc. were superior. As for other coating materials tested in this study, superior materials against certain deterioration factors may be inferior against other factors. Accordingly, in order to select suitable coating materials for the use, it is thought that investigation of suitability through experiment should precede selection of materials, especially for unusual coatings or paints.

1. INTRODUCTION

Steel is an indispensable material in present civilization, and demand of it in construction of various kinds of structures such as bridges is increasing. However, steel has also inherent weak point that it is corroded in natural condition. It is reported that loss by corrosion of metal reached 2~3% of GNP in western industrial nations. [1] Social and economic losses are tremendous if containing not only direct loss by corrosion but also indirect loss such as suspending of operation due to repairs, decrease of effectiveness, reconstruction, excessive design, etc. According to Louthan's report [2], rehabilitation cost containing both of direct and indirect loss in USA was estimated about 250 billion dollars per year. In addition, corrosion problem also has a danger that safety accidents or loss of lives can occur.

Protective coating is one of the most convenient and effective methods for protection of steel. However, life of coating is much shorter than that of structure, and therefore maintenance coating is very important. According to another study [3] carried out in KEC (Korea Expressway Corporation), mean life of coating applied on steel bridges is about 12~14 years. If service life of a structure should be maintained for 50 years, maintenance coating is required 3 times during service. Recently, importance of maintenance coating is more emphasized, due to increase of amount of used chloride-containing deicers such as calcium chloride and sodium chloride. According to Lee et al [4], used amount of deicers has been abruptly increased since 2003 when new scattering method using prewetting salt was introduced. In addition, increase of structures under marine environment is also threatening element in maintenance of protective coating.

In this study, in order to suggest general guidelines for select suitable coating system, performances of various coating systems that can be used for protection of steel bridges including chlorinated rubber and inorganic zinc/epoxy/urethane used the most in Korea were evaluated by complex accelerated test.

2. EXPERIMENTAL

2.1 Materials and Preparation of Specimens

Coating materials used for test were 12 coating systems as shown in Table 1. For surface preparation, 150×70×3mm hot rolled steel plates were prepared with 30～40 ㎛ of surface roughness by grit blast cleaning after degreasing. Application of paint was carried out by air spray to form optimum dry film thickness recommended by supplier.

Table 1. Coating systems used for test

Abbreviation	Coating system	Primer	Intermediate coat	Topcoat	No. of coat
C/U	Ceramic/urethane	Ceramic		Ceramic urethane	2
MCU/U1	Moisture-curing urethane/urethane1	Moisture- curing urethane		Urethane	2
MCU/U2-1	Moisture- curing urethane/urethane2-1	Moisture- curing urethane		Urethane	2
MCU/U2-2	Moisture- curing urethane/urethane2-2	Moisture- curing urethane		Urethane	2
Al/E/U	Al-epoxy mastic/ epoxy mastic/urethane	Al-epoxy mastic	Epoxy mastic	Urethane	3
Sil	Acrylic silicone	Acrylic silicone			1
CR	Chlorinated rubber	Chlorinated rubber MIO	Chlorinated rubber	Chlorinated rubber	3
IOZ	Waterborne inorganic zinc	Waterborne inorganic zinc			1
ZEU	Waterborne inorganic zinc/epoxy/urethane	Waterborne inorganic zinc	Epoxy	Urethane	3
Zn/E	Zn metalizing/epoxy	Zn metalizing		Epoxy	2
Al/E	Al metalizing/epoxy	Al metalizing		Epoxy	2
Gal/E	Galvalume metalizing/epoxy	Galvalume(Al 55%/Zn 45%) metalizing		Epoxy	2

2.2 Deterioration and Evaluation of Specimens

Test specimens were exposed in complex deterioration cycles considering various deterioration factors in the nature such as sunlight, rain, freeze-thaw and salt. In the first step, *UV-condensation*, test specimens were repeatedly exposed in ultraviolet ray at 60℃ for 8h and condensation at 40℃ for 4h, in turn for 7 days using QUV®. For irradiation of ultraviolet ray, UVB-313 lamps that mainly emit rays at 313nm of wavelength as shown in Figure 1 were used. In the second step, *freezing*, test specimens were exposed in -20 ℃ chamber for 1 day. In the third step, *immersion*, test specimens were immersed in 5% NaCl solution at 35℃ for 6 days. If once execution of the 3 steps is regarded as 1 cycle, total 10 cycles were carried out over again. The schematic test procedure is showed in Figure 2.

For all specimens, blistering, chalking, checking/cracking and rust grades with elapsed time were evaluated according to ASTM standards [5~9]. Color differences were measured using X-Rite® SP88 Spectrophotometer according to ASTM D 2244 [10], ASTM E 805 [11] and ASTM E 1347 [12],

and adhesion test was carried out using Elcometer® Adhesion Tester according to ASTM D 4541 [13].

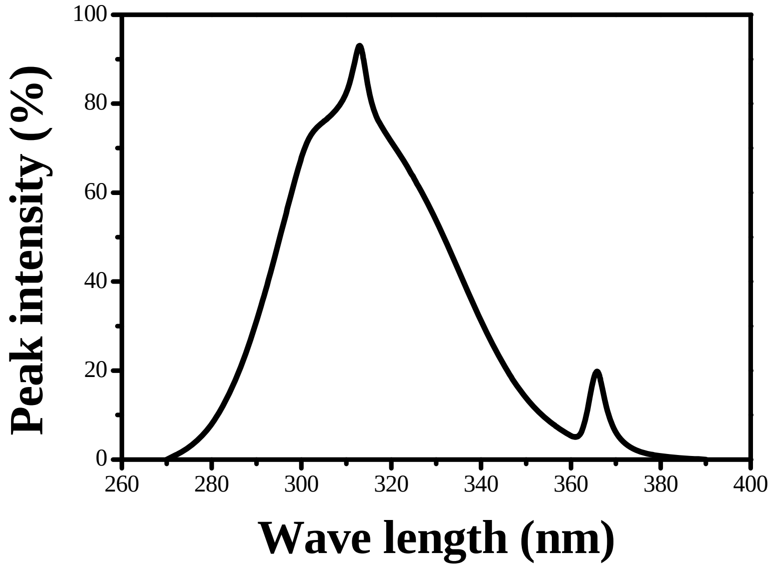

Figure 1. Spectrum energy distribution of UV lamps

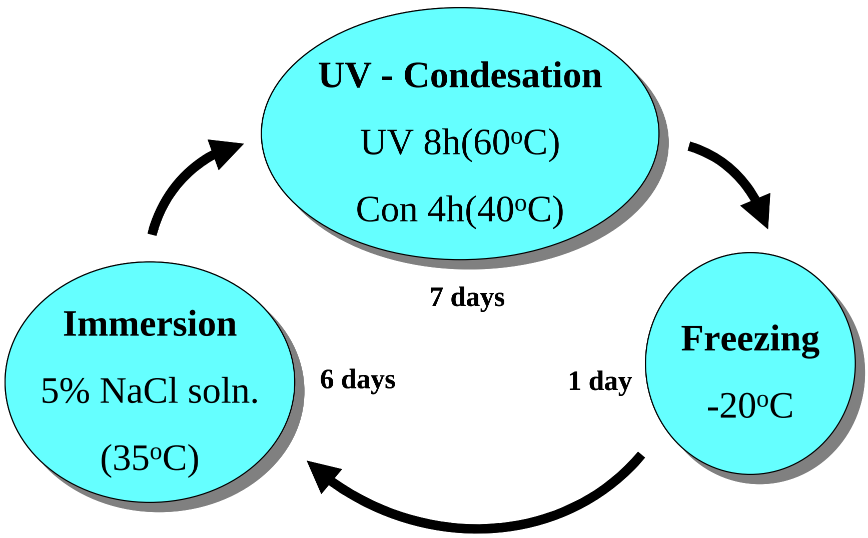

Figure 2. Method for deterioration of specimens

3. RESULTS AND DISCUSSION

3.1 Blistering Grade

In evaluation of blistering grade, waterborne inorganic zinc/epoxy/urethane was the worst, and waterborne inorganic zinc, ceramic/urethane, and 2 kinds of moisture-curing urethane/urethane were the best as shown in Figure 3. It is thought that blisters which appeared on waterborne inorganic zinc/epoxy/urethane specimen are osmotic blisters caused by zinc salt that had existed on inorganic zinc primer coat before intermediate coat was applied from the fact that they appeared on early stage

of test. Generally, osmotic blistering occurs when coating is applied on surface contaminated by water-soluble salts. Mechanism of osmotic blistering is showed in Figure 4. Since coating acts as selective permeable membrane, water can permeate through coated film, but salts cannot. Osmotic pressure made by concentration difference between inside and outside of coated film accelerates permeation of water. Permeated water is diffused through film layer, and blisters grow until concentrations of 2 regions are equivalent. Mechanism of osmotic blistering is showed in Figure 4.

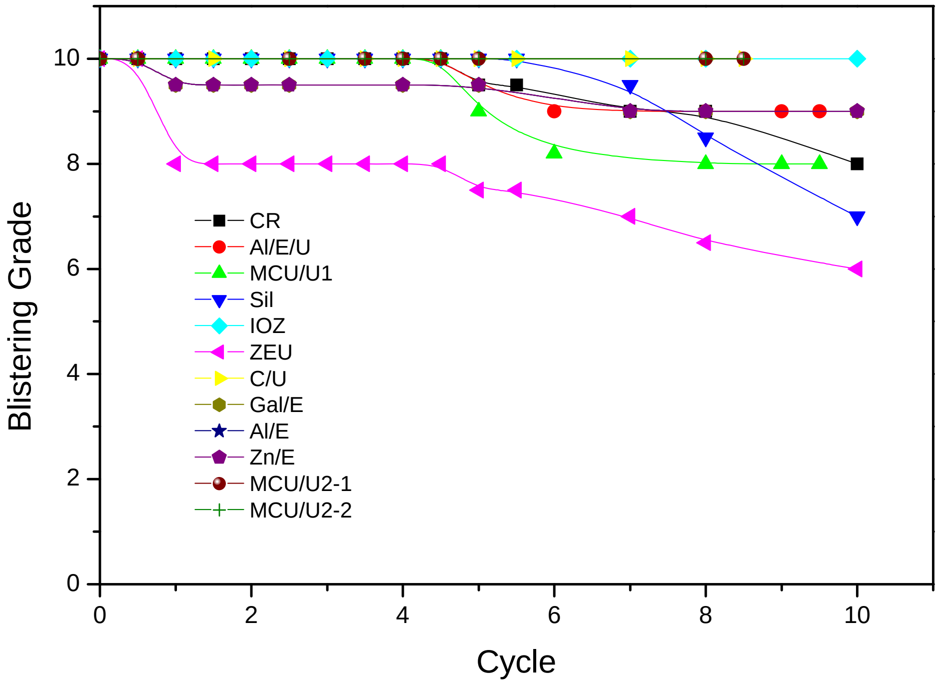

Figure 3. Blistering grades by ASTM D 714

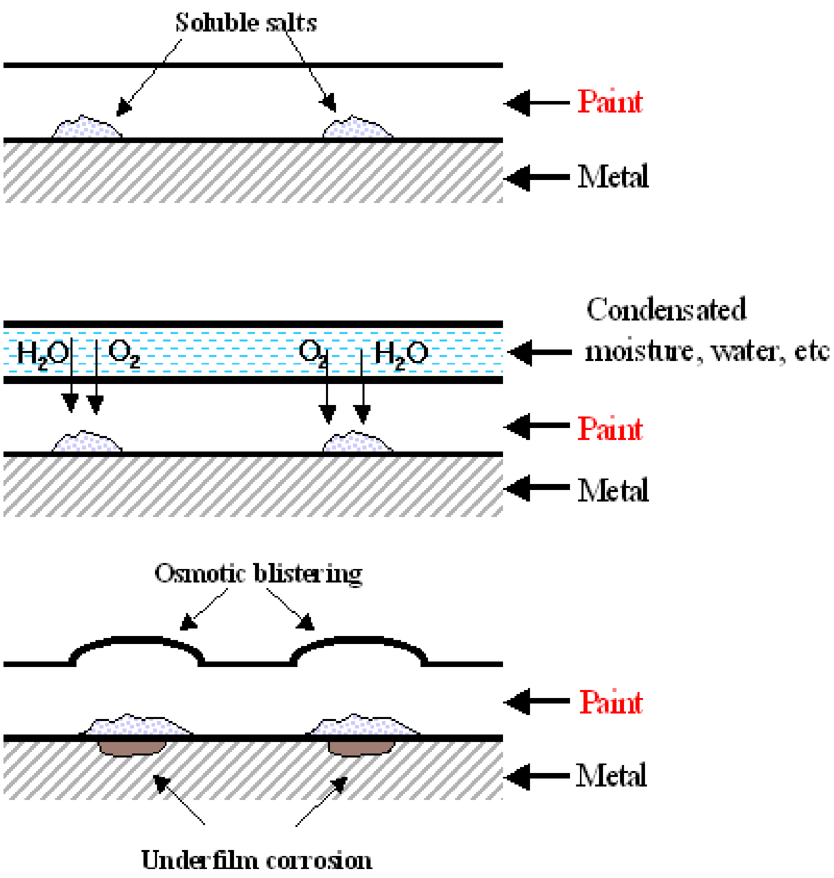

Figure 4. Mechanism of osmotic blistering

3.2 Deterioration by UV

Chalking is one of the most frequently appeared coating failures. The mechanism of chalking is essentially one where the coating binder tends to gradually disintegrate by UV, leaving the surface covered with the pigments that have been held on the surface by binder. This process continues until the surface coating is worn through, at which time the primer is visible or corrosion begins to occur on the substrate [14]. Chalking grade can be criterion of stability against photochemical reaction by UV.

Chalking grades of test specimens in this study are showed in Figure 5. From the result that chalking grades of acrylic silicone, ceramic/urethane and one kind of moisture-curing urethane/urethane did not decrease under grade 8, it is thought that the 3 coating systems were most superior in stability against photochemical reaction by UV. On the other hand, chalking occurred most rapidly for 3 kinds of metalizing (galvalume, zinc and aluminum) with epoxy topcoat. Generally, epoxy coating is vulnerable to UV-induced breakdown due to carbon to carbon double bond (-C=C-) in aromatic ring, where one carbon atom excited by UV forms highly reactive free radical that results in the occurrence of many complex intrapolymeric reactions. These reactions may include chain splitting, depolymerization, and even the evaporation of smaller polymeric fragments [15]. Accordingly, it is desirable that epoxy used as topcoat is substituted with more sustainable material such as urethane.

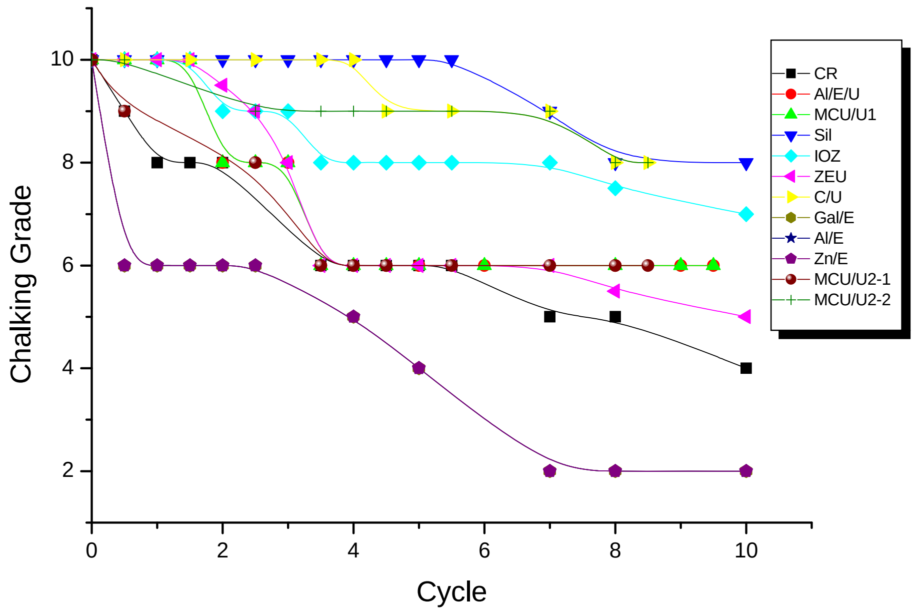

Figure 5. Chalking grades by ASTM D 4214

In order to confirm above results, color differences measured by spectrophotometer are showed in Figure 6. Test results showed similar trend to the chalking grade. The fastest decolorized coating in the first stage was epoxy topcoat used in metalizing, the second one was moisture-curing urethane/urethane2-1, and the third one was chlorinated rubber, while the slowest decolorized coating systems were ceramic/ urethane and moisture-curable urethane/urethane2-2.

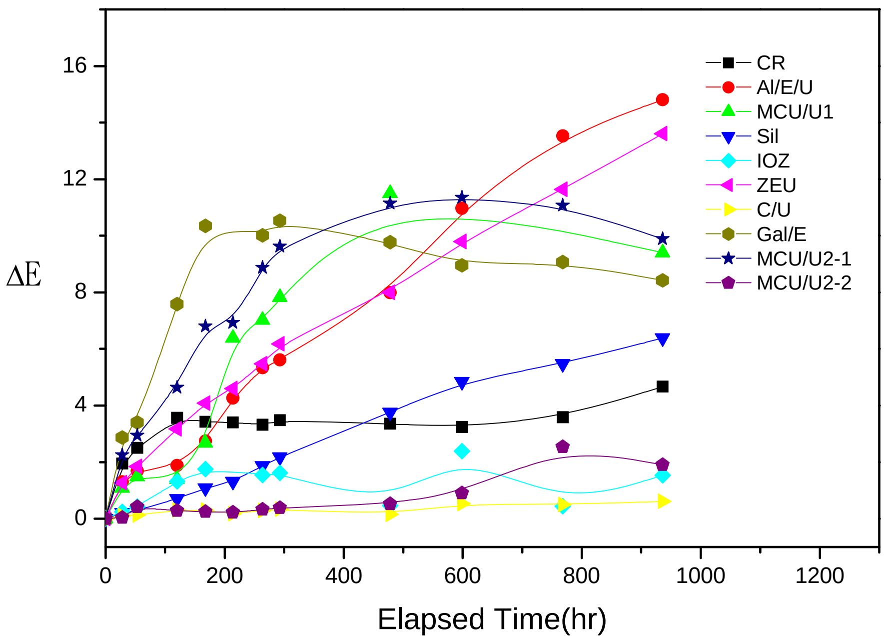

Figure 6. Color differences measured by spectrophotometer

3.3 Checking/Cracking Grade

Evaluated checking/cracking grades are showed in Figure 7. Checking of a coating can be described as small breaks in a coating surface formed as the coating is deteriorated and becomes harder and more brittle. Checking is a surface phenomenon and does not penetrate the full depth of the coating. On the other hand, cracking is not a surface problem, but one where the breaks in the coating extend from the surface through to the substrate. [14] In this study, slight cracking appeared only on water-soluble inorganic zinc specimen.

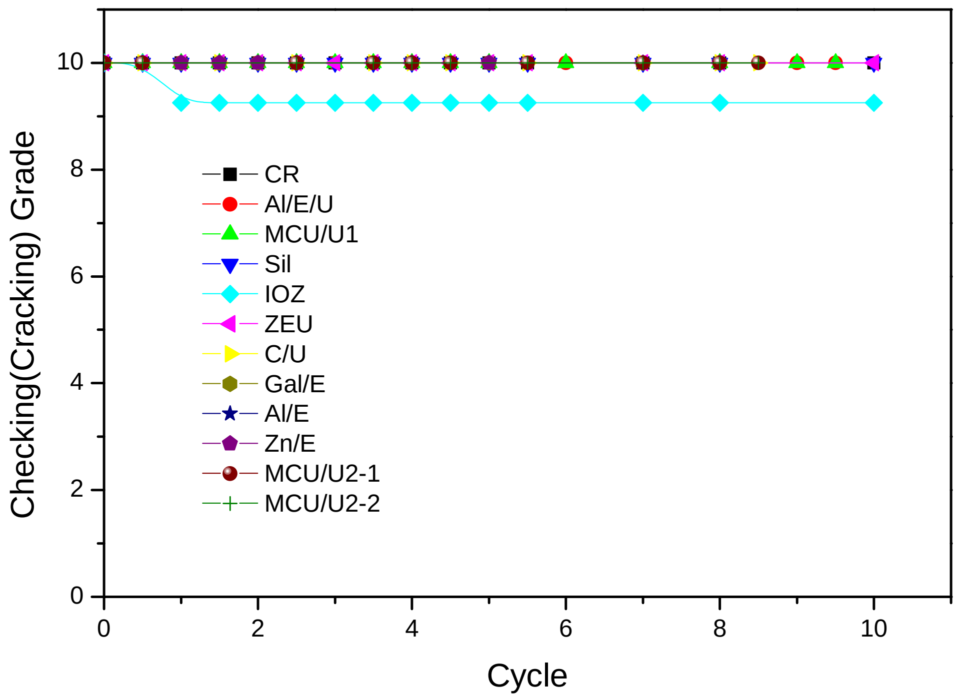

Figure 7. Checking/cracking grades

3.4 Corrosion Resistance

Rust grades with exposure time are showed in Figure 8. The most superior coating systems in corrosion resistance were ceramic/urethane, 2 kinds of moisture-curable urethane/urethane, and 3 kinds of metalizing that maintain grade 10 until the end of test. Chlorinated rubber coating specimen maintained similar corrosion rate to most of other specimens, though it was corroded fast in the early stage of test. Rust grade of acrylic silicone was lowest at the end of test, though it was high in the early stage of test. From the result, it is thought that acrylic silicone single coat is not suitable for protective coating. However, acrylic silicone coating, in spite of its inferiority in corrosion resistance, is expected to be substituted for urethane topcoat to make coating performance be enhanced, since it was more stable than most of urethane photochemically in the evaluation of chalking grade and color difference measurement.

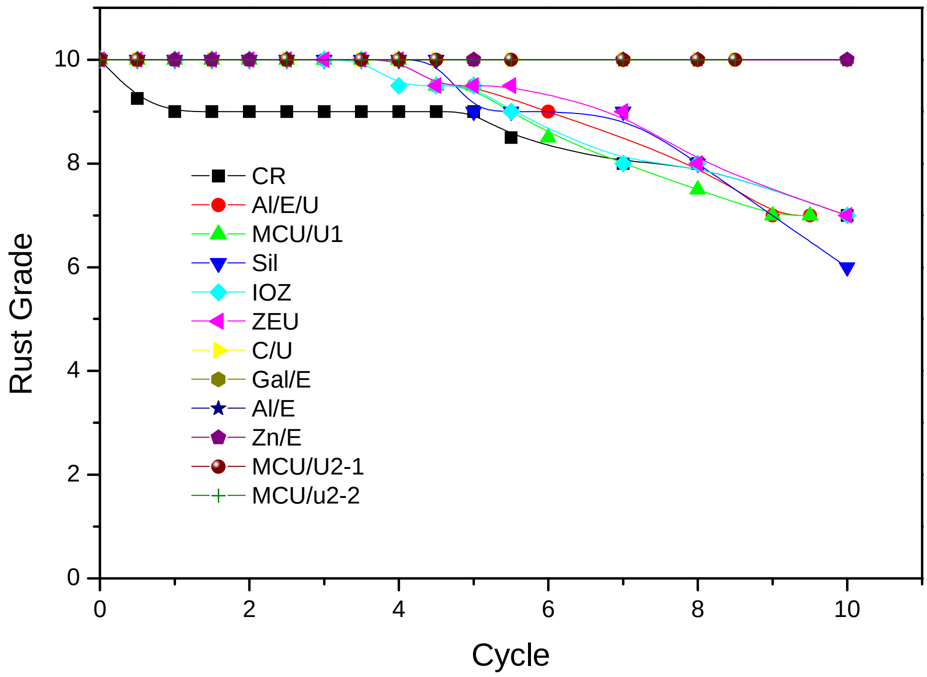

Figure 8. Rust grades by ASTM D 610

3.5 Adhesion Test

Measured results of adhesion are showed in Table 2. It is thought that coat-substrate adhesion is higher than intercoat adhesion, from the result that all the breakdown sections were coat to coat except acrylic silicone applied as single coat. The most superior coating systems in adhesion were Al-epoxy mastic/epoxy mastic/ urethane, moisture-curing urethane/urethane2-1, and ceramic/urethane. Three kinds of metalizing also showed high adhesion values of more than 4Mpa, but those were adhesion between metalizing and epoxy. It is expected that adhesion of the metalizing itself will be much higher than the values measured in this test.

Table 2. Adhesion test results

Coating system	Breakdown Section	Adhesion (MPa)
Chlorinated rubber	P - I	4.05
Ceramic/urethane	-	4.80<
Al-epoxy/epoxy/urethane	P – I	5.25
Waterborne inorganic zinc	-	3.70<
Waterborne inorganic zinc/epoxy/urethane	P – I	0.97
Acrylic silicone	Substrate - Coat	2.07
Galvalume metalizing/epoxy	P - T	4.20
Al metalizing/epoxy	P – T	4.40
Zn metalizing/epoxy	P – T	4.80

Moisture-curing urethane/urethane1	P – T	3.08
Moisture-curing urethane/urethane2-1	P – T	5.63
Moisture-curing urethane/urethane2-2	P - T	4.83

* P : primer, I : intermediate coat, T : topcoat

4. CONCLUSIONS

From the evaluation of various coating materials for steel bridges through accelerated test exposing test specimens to complex deterioration factors, we concluded that:

(1) Ceramic/urethane, moisture-curing urethane/urethane, etc. were superior in overall coating performances such as corrosion resistance, photochemical stability, and adhesion.
(2) It is desirable that epoxy used as topcoat in metalizing specimens is substituted with more sustainable material such as urethane, because epoxy coating is vulnerable to UV-induced breakdown due to carbon to carbon double bond (-C=C-) in aromatic ring.
(3) Acrylic silicone single coat is not suitable for protective coating. However, it is expected to be substituted for urethane topcoat to make coating performance be enhanced, since it was more stable than most of urethane photochemically.
(4) In order to select suitable maintenance coating materials for the use, it is thought that investigation of suitability through experiment should precede selection of materials, especially for unusual coatings or paints.

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